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ISSUES OF STRATOSPHERE-TROPOSPHERE EXCHANGE IN THE MIDDLEWORLD

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ABSTRACT

Understanding the dynamical, chemical and physical processes that control water vapor, ozone, radical constituents, aerosols, and clouds and their impact on the radiative balance of the Upper Troposphere and Lower Stratosphere (UTLS) is critical for advancing the reliability of predictions of climate change or of trends in global air quality. The UTLS is a highly coupled region: dynamics, chemistry, microphysics and radiation are fundamentally interconnected. Characterizing the transport processes and their contribution to the constituent distribution in the UTLS is an important first step toward a better quantification of chemical and microphysical processing in this region. In this presentation, we discuss a set of outstanding issues with a focus on the characterization of the extratropical tropopause and modeling mixing.

INTRODUCTION

Stratosphere-troposphere exchange (STE) in the middleworld is a key controlling factor for trace gas distribution in the upper troposphere and lower stratosphere (UTLS) [e.g., Holton et al., 1995]. Despite recent progress in modeling and observation of STE [e.g., Zahn et al., 2000; Fischer et al., 2000; Hoor et al., 2002; Wernli and Bourqui, 2002; Stohl et al., 2003a,b; Sprenger et al., 2003; Cooper et al., 2003; Ray et al., 2004], large uncertainties remain in quantifying the effect of STE on ozone budget in the upper troposphere. To improve our ability to quantify STE of chemical species in the middleworld, a set of outstanding issues needs to be addressed with combined efforts of observations and modeling. How do we quantify the effect of mixing on the trace gas transport across the tropopause? What is the relevant transport boundary in the calculation of STE of chemical species? What is the role of the subtropical jet (STJ) in mixing and exchange of chemical species? What is the relative importance of long range frontal uplifting versus local deep convection in redistributing tracers? The possibility of long-term routine measurement of chemical tracers and dynamical variables in the extratropical tropopause region within the SOFIA Upper Deck project presents an excellent opportunity for the UTLS research community to investigate these issues.

CHEMICAL TRANSITION ACROSS THE EXTRATROPICAL TROPOPAUSE

One of the difficulties of quantifying STE in the extratropics is the identification and characterization of the tropopause. Because chemical tracers exhibit large vertical gradients across the tropopause, improper identification of the transport boundary between the stratosphere and troposphere can produce large errors in calculations of STE of chemical tracers. A number of important questions need to be answered by observations: What is the relevant transport boundary for STE of chemical tracers? Should we characterize the E-tropopause as a surface or a layer? If a layer, how thick is the layer? In situ observations of tracers indicate that a transition layer exists [Fischer et al., 2000; Hoor et al., 2002; and WMO 2003]. Further recent analysis shows that, statistically, this transition layer is centered on the thermal tropopause [Pan et al., 2004] rather than, for example, a specific potential vorticity value.

Analyses based on limited observations also show that the transition spans a broader vertical range in the vicinity of the STJ, but is more abrupt distant from the jet [Pan et al., 2004]. An example of an abrupt transition is given in Figure 1. A contrast of the chemical transitions across the tropopause near and at distant from the STJ is illustrated by Figure 2. Routine observations of a set of chemical tracers during SOFIA project will provide a much needed database to address these issues statistically.

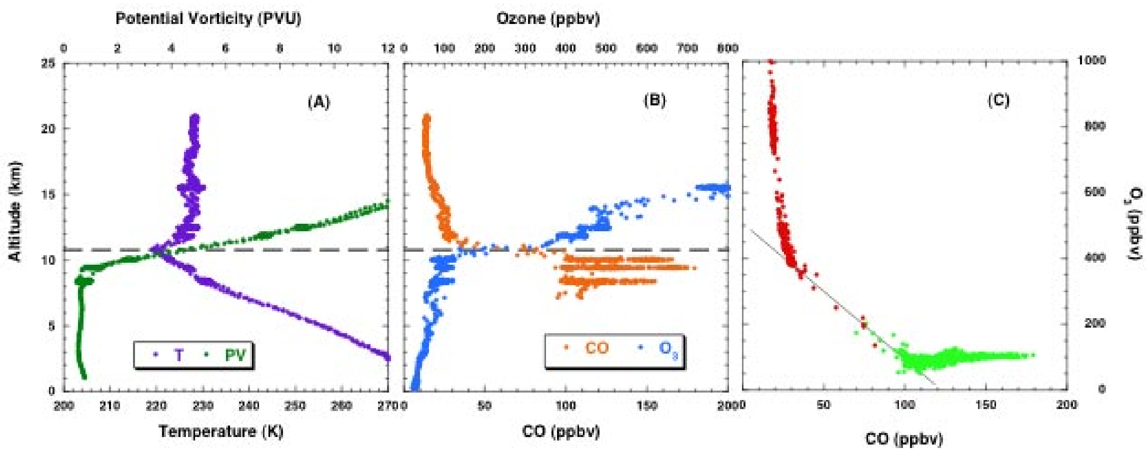

Fig. 1. Left and center panels show temperature, PV, CO and O_3 profiles from a stacked flight on July 10, 1997, near Fairbanks, during the Photochemistry of Ozone Loss in the Arctic Region In Summer (POLARIS) campaign. Data from both ascending and descending portions of the flight are shown. The thermal tropopause, represented by dash lines, is at 10.8 km. The tracer profiles indicate that abrupt change occurs in chemical constituents near the thermal tropopause. The right panel demonstrates the effectiveness of O_3-CO relationship in characterizing the chemical transition between stratosphere (red) and troposphere (green) [Pan et al., 2004].

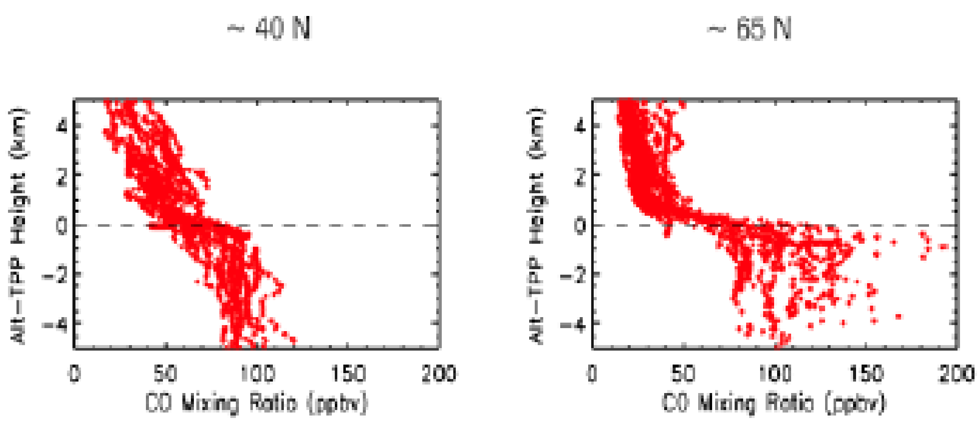

Fig. 2. CO profile as function of altitude relative to the thermal tropopause measured at two latitude locations. The left panel shows profiles near Moffet Field. The right panel shows profiles near Fairbanks. [Pan et al., 2004]

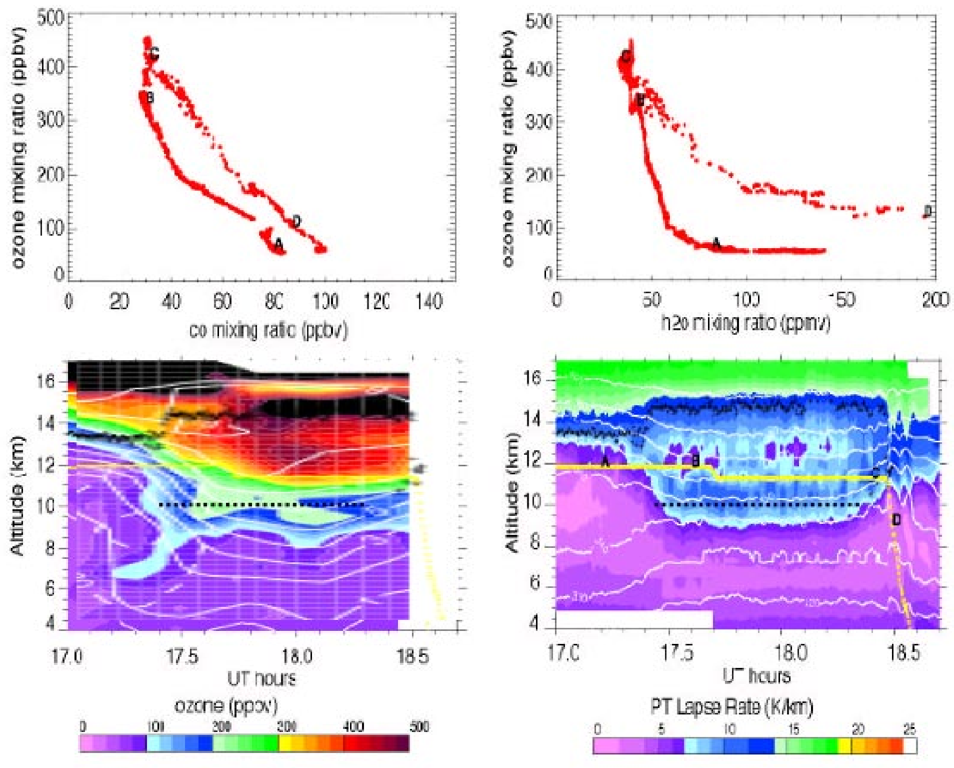

Fig. 3. A case of intrusion. Yellow line shows the DC-8 flight alt. Top panels are O_3-CO and O_3-H_2O relationship from the in situ measurements onboard DC-8. Lower-left is ozone from the DIAL, over plotted with U wind (white dashed) and PV (white solid) from ECMWF, the lower-right panel shows the potential temperature lapse rate (static stability) derived from MTP. Small black crosses indicate thermal tropopause from MTP measurement. The black dotted line marks the position of a likely second tropopause.

MODELING MIXNG

Dynamical processes near the STJ play important roles in STE. While the jet core exhibits a barrier to isentropic mixing, the synoptic scale and mesoscale dynamics around the jet, in conjunction with large-scale wave breaking, produce irreversible exchange which poses a considerable challenge to model simulation. Figure 3 shows an example of an event observed during the SONEX experiment. The measurements were made onboard NASA DC-8 research aircraft. The ozone cross section from the DIAL LIDAR, the thermal structure including the tropopause from the MTP, the relationships of tracers (O_3, CO, and H_2O) together gives an example for the kind of intrusion and mixing in the vicinity of the STJ. Observations of this kind covering greater latitudinal range are rare.

Furthermore, characterizing these processes and quantifying mixing in models is an important step toward quantifying STE in the extratropics on the global scale. Figure 4 shows some preliminary results from a new model, the Chemical Lagrangian Model for the Stratosphere (ClaMS) [McKenna et al., 2002; Konopka et al., 2004], that has demonstrated success in simulating mixing in the vicinity of the polar vortex. These new model results also require assessment from observations. The payload capability of SOFIA upper deck, the initial location of the operation, together with the altitude/range of the flight make it a unique platform for expanding our database for mixing around the STJ and for improving new models.

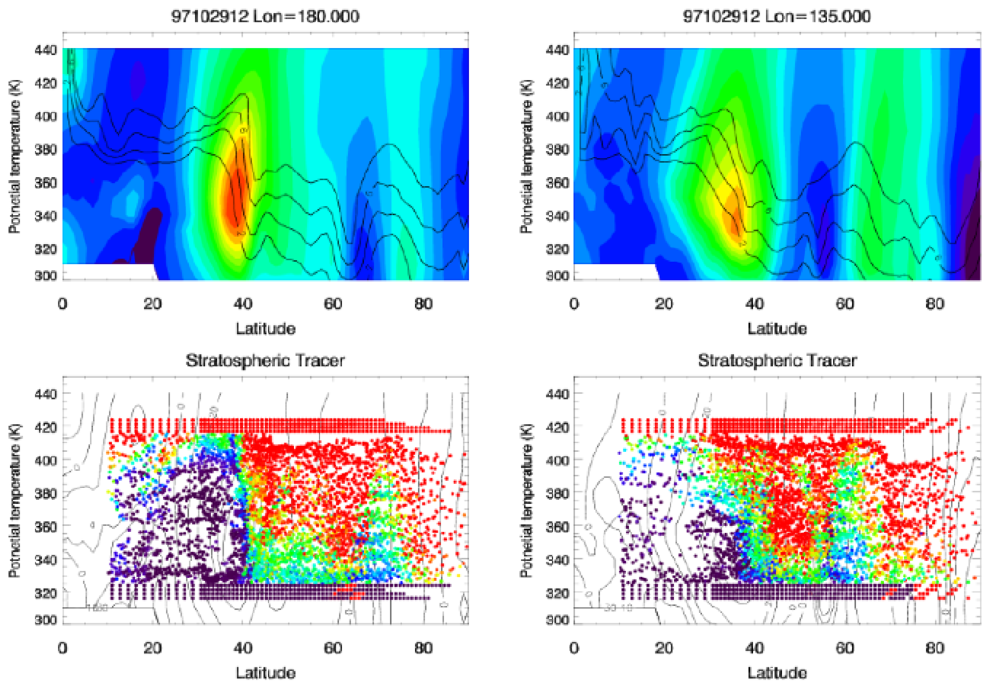

Fig. 4. The upper panels show vertical cross-sections of zonal wind (color image) and potential vorticity (black contours represent 2,4,6, and 8 PVU isopleths) from ECMWF data. The subtropical jet location and spatial extent is indicated by the wind maximum. Outside the tropics, the 2 PVU potential vorticity contour approximately represents the tropopause. Depending on the season, the 400 K potential temperature surface roughly corresponds to 15 km altitude in the midlatitudes. The bottom panels show the model simulations of mixing near the STJ using an ozone-like tracer (red is stratospheric value, purple tropospheric value, others indicate mixing). Left panels show a case of a strong jet, where the jet core has a barrier effect to isentropic mixing for a large range of potential temperature. The right panels show a cross-section near a relatively weak jet. Note in both cases, mixing occurs on the top of the jet and on the cyclonic side of the jet.

A challenge for understanding and modeling the seasonality of STE is to characterize the contribution of dynamical processes from large to small scales. The imminent launch of the NASA AURA satellite together with the available and new high altitude research aircraft, such as NASA WB57 and NSF HIAPER, presents a new opportunity for simultaneous measurement of the tropopause region across scales. The application of SOFIA Upper Deck can make a significant addition to this effort.

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